A REVIEW OF ARTIFICIAL INTELLIGENCE IN EDUCATION: WHAT IS AHEAD, WHAT IS LEFT BEHIND AT GLOBAL SCALE?

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Abstract

This narrative review synthesizes recent research on artificial intelligence (AI) in education to address gaps in understanding its diverse roles, integration strategies, and pedagogical implications. The review aims to evaluate AI integration within curricula and instructional practices, examine AI literacy development, identify inclusive pedagogical strategies, compare adoption challenges including ethics and equity, and analyze AI's role in fostering critical thinking and creativity. Literature published between 2020 and 2025 was identified through searches of the Scopus, Web of Science, PubMed/MEDLINE, and arXiv databases, supplemented by AI-assisted semantic search, and a purposively selected body of 86 sources comprising peer-reviewed journal articles, books, conference proceedings, and preprints was retained as representative evidence for critical synthesis. A thematic analysis of empirical and theoretical studies across global K-12, higher education, and professional contexts was conducted, focusing on AI literacy and educator preparedness, curriculum design, pedagogical effectiveness, inclusivity, and ethics. Findings reveal that AI-enabled personalized and adaptive learning can significantly enhance student engagement and outcomes while supporting diverse learner needs; however, equitable access and infrastructure disparities limit inclusivity. Curriculum frameworks emphasize interdisciplinary AI literacy integrating ethical and technical competencies, yet standardization and comprehensive coverage remain insufficient. Educator readiness is critical but hindered by knowledge gaps and limited professional development, affecting effective AI adoption. Ethical concerns, including data privacy and algorithmic bias, are widely recognized but inadequately addressed in practice. Collectively, these findings underscore AI's transformative potential in education contingent on balanced curriculum design, ethical integration, and robust teacher support. The review informs educators, policymakers, and researchers on effective AI embedding strategies to prepare learners for an AI-driven future.

Keywords

Artificial Intelligence, Educational Technology, Techno-Pedagogy, AI Ethics, AI Literacy

1. Introduction

1.1. Context

Research on artificial intelligence (AI) in education has emerged as a critical area of inquiry due to its transformative potential in reshaping both technology teaching, e.g., thinking and teaching about AI as a technology, and educational technology, using AI to support learning processes across educational levels more generally (Stolpe and Hallström, 2024; Xiao et al., 2025). The evolution of AI integration in education spans from early computational literacy initiatives to the current emphasis on AI literacy and adaptive learning systems (Casal-Otero et al., 2023; Yue et al., 2022). This progression reflects growing societal and economic demands for AI competencies, with AI literacy increasingly recognized as an essential technological competency for preparing students for future societal challenges (Wang & Lester, 2023; Zhao, 2025). Notably, AI-driven personalized learning platforms and intelligent tutoring systems have demonstrated improvements in student engagement and academic outcomes, underscoring the practical significance of AI in education (Deckker et al., 2025; Salendab et al., 2026). However, though statistics reveal a rapid increase in AI adoption in educational institutions, there are disparities in access highlighting equity concerns (Li et al., 2024; Westover, 2025).

Despite these advances, a specific problem persists in effectively integrating AI into education curricula, particularly in K-12 and higher education contexts (Dubey & Crevar, 2025). There is a notable knowledge gap regarding standardized frameworks for AI literacy, pedagogical strategies, and teacher preparedness to deliver AI content effectively (Fissore et al., 2024; Yau et al., 2023; Yue et al., 2024). Competing perspectives exist: some advocate for AI as a tool to enhance personalized learning and administrative efficiency, while others caution against overreliance on AI, emphasizing ethical challenges and the preservation of human-centered pedagogy (Yadav, 2024). The consequences of this gap include inconsistent AI education quality, limited teacher confidence, and potential exacerbation of educational inequities (Addo, 2023; Familoni & Onyebuchi, 2024).

The conceptual framework for this review defines AI literacy as encompassing knowledge of AI technologies, skills to interact with AI systems, and ethical understanding of AI's societal impacts (Chiu et al., 2024; Tadimalla & Maher, 2024). This framework situates AI literacy within technological literacy and computational thinking, emphasizing the integration of technical, socio-ethical, and reflective competencies (Stolpe & Hallström, 2024; Weng et al., 2024). The relationships among these concepts guide the examination of AI's role in curriculum design, instructional methods, and teacher education (Black et al., 2024; Lim, 2024).

The purpose of this review is to synthesize current research on AI integration in education, focusing on curriculum development, pedagogical approaches, and teacher readiness (Garzón et al., 2025; Yue et al., 2024). This review aims to fill the identified gaps by providing a comprehensive analysis that informs educators, policymakers, and researchers on effective AI literacy implementation across educational contexts (Lin & Van Brummelen, 2021). The value added lies in consolidating interdisciplinary perspectives and highlighting best practices and challenges to support equitable and ethical AI education (Tahura et al., 2026; Yadav, 2024).

Analytical frameworks incorporate thematic synthesis and conceptual mapping to organize findings on AI literacy components, curriculum models, and instructional strategies (Heo, 2025; Rüütmann & Läänemets, 2025). The review is structured to first contextualize AI in education, then explore curriculum integration, followed by customized learning, intelligent tutoring systems, teacher preparation and pedagogical innovations, concluding with recommendations for future research and practice (Lin & Van Brummelen, 2021; Stolpe & Hallström, 2024).

1.2. Purpose and Objectives of the Review

The objective of this report is to examine the existing research on "AI in education" in order to elucidate the multifaceted roles, integration strategies, customized learning, intelligent tutoring systems and pedagogical implications of artificial intelligence in education frameworks. This review is important as AI technologies increasingly permeate educational environments, reshaping curriculum design, instructional methodologies, and learner engagement. By synthesizing current knowledge, the report aims to provide a comprehensive understanding of how AI contributes to technological literacy, fosters inclusivity, and addresses challenges such as ethical considerations and equitable access. Ultimately, the review seeks to inform educators, policymakers, and researchers about effective approaches to embedding AI in education, thereby preparing learners for an AI-driven future.

Specific objectives:

1) To evaluate current knowledge on AI integration into education curricula and instructional practices.
2) Benchmarking of existing approaches to AI literacy development in education across diverse educational levels.
3) Identification and synthesis of pedagogical strategies that leverage AI to enhance inclusivity and personalized learning.
4) To compare challenges and opportunities reported in AI adoption for education, including ethical and equity concerns.
5) To deconstruct the role of AI tools in fostering critical thinking, creativity, and problem-solving in education.

2. Methodology

2.1. Review Approach and Rationale

This chapter adopts a narrative (traditional) review design with a thematically organized synthesis, consistent with the aims and format of a book chapter intended to orient readers to the field. This methodological choice also reflects the character of the field itself. Research on AI in education is expanding rapidly, is terminologically heterogeneous (spanning labels such as "AI literacy," "intelligent tutoring systems," "adaptive learning," and "machine learning education"), and is distributed across diverse publication venues, disciplines, and educational contexts. The aim of this review is not an exhaustive quantitative mapping of every published study, but a critical, interpretive synthesis that identifies conceptual themes, tensions, and gaps across the literature and connects them to implications for curriculum design, pedagogy, equity, and policy.

For this purpose, a narrative review offers distinct advantages over systematic or scoping designs. It permits the integration of methodologically diverse contributions such as empirical studies, theoretical and conceptual papers, policy-oriented analyses, and emerging preprints that would be difficult to synthesize under a single appraisal framework, and it allows the researchers' domain expertise to guide the selection of the most conceptually significant works rather than constraining synthesis to what standardized search strings happen to retrieve. Narrative reviews are widely recognized as an appropriate design when the goal is interpretation, theory development, and agenda-setting in a fast-moving and conceptually fragmented field, as is the case for AI in education (Grant & Booth, 2009; Greenhalgh et al., 2018).

2.2. Literature Identification and Selection

To identify relevant literature published between January 2020 and December 2025, searches were conducted in the Scopus, Web of Science (WoS), PubMed/MEDLINE, and arXiv databases, using combinations of AI-related terms ("artificial intelligence," "machine learning," "deep learning," "natural language processing," "intelligent tutoring systems") with education-focused terms ("education," "learning," "teaching," "pedagogy"). These database searches were supplemented by AI-assisted semantic search (SciSpace), which complements Boolean keyword matching by surfacing conceptually related work across the field's heterogeneous vocabulary. All sources ultimately included in the review were verified by the authors against their original records, and all relevance judgments were made by the researchers rather than delegated to the tool.

From the retrieved literature, sources were selected purposively rather than exhaustively, following the logic of information-rich case selection appropriate to narrative synthesis. Four criteria guided inclusion: (1) substantive relevance: the source directly addressed at least one of the review's guiding questions (AI integration in curricula and instruction, AI literacy and educator preparedness, personalized and adaptive learning, inclusivity and equity, or ethical challenges of AI adoption); (2) conceptual or empirical contribution: the source offered original findings, a distinct theoretical framing, or a synthesis that advanced understanding beyond studies already selected, such that redundant confirmations of already-represented findings were not added; (3) contextual breadth: sources were deliberately balanced to cover K-12, higher education, and vocational settings across diverse geographic regions, so that no theme rested on a single context; and (4) quality and recency: priority was given to peer-reviewed journal articles published between 2020 and 2025, with books, conference proceedings, and preprints admitted only where they offered significant contributions not yet represented in the journal literature. Sources were excluded if they were not substantively concerned with AI in educational settings or fell outside this window. Selection continued until thematic saturation was reached, that is, until additional sources no longer introduced new themes or materially altered existing ones, yielding a final corpus of 86 sources spanning global K-12, higher education, and professional contexts, which constitutes the evidence base cited throughout this chapter.

2.3. Analysis and Synthesis

The selected sources were read in full and analyzed thematically. An inductive coding of key findings, arguments, and recommendations was carried out and iteratively grouped into the organizing themes of the review: (1) AI literacy and educator preparedness, (2) curriculum design and integration, (3) pedagogical effectiveness of personalized and adaptive learning, (4) inclusivity and equity, and (5) ethics and governance. Within each theme, findings were compared across educational levels and geographic contexts to surface convergences, contradictions, and underexplored areas. Consistent with the narrative review design, the synthesis is interpretive and critical rather than tabulative: the discussion foregrounds representative and conceptually significant evidence for each theme and uses it to articulate research trends, gaps, and future directions in the field of AI in education.

3. A Comprehensive Review of AI in Education

This chapter reviews the literature on AI in education through a thematically structured synthesis, preceded by a brief qualitative chronological descriptive overview that situates the evolution of the field. The chapter adopts thematic analysis (Braun & Clarke, 2012) as the primary analytical contribution, allowing findings

across educational levels, regions, and methodologies to be integrated into a coherent narrative, while the initial chronological review provides supplementary historical context. The thematic analysis is followed by an overview of strengths and weaknesses of AI integration in education discussed throughout the reviewed literature, and finally an overview of ongoing discussions in contemporary works.

3.1. Chronological Review of the Literature

The chronological development of literature on AI in education reveals a gradual shift from early curriculum conceptualization toward systemic, ethical, and adaptive implementations. Early work focused on defining AI concepts and integrating them into computing curricula, while later studies expanded toward interdisciplinary approaches, K–12 inclusion, teacher preparation, and ethical governance. Most recent research emphasizes generative AI, adaptive learning systems, inclusivity, and responsible innovation. While the 'Pre-2000' era belongs to the history of computer science philosophy, the 'Post-2000' era belongs to the history of functional technology. Starting at 2000 filters out the 'AI Winters' and focuses the reader on the specific evolutionary path that led directly to the current generative AI boom. By anchoring the chronology in the year 2000, we focus the narrative on the definitive shift from the rigid, rule-based logic of the 20th century to the modern era of applied machine learning, capturing the precise historical juncture where the convergence of massive internet-scale datasets, statistical modeling, and high-performance GPU hardware transformed artificial intelligence from a lab-bound academic theory into the scalable, functional powerhouse that directly fuels today's generative revolution. Table 1 summarizes this chronological development of the literature across six periods.

Table 1

Chronological Review of Literature

Year Range	Research Direction	Description
2001–2010	Foundations and Early Curriculum Development	Early studies concentrated on developing integrated AI curricula and exploring AI concepts for learners, focusing on foundational knowledge and pedagogical frameworks in computing education. Emphasis was placed on motivating students through AI-related projects and integrating AI as a disciplinary subject.
2011–2015	Expansion of AI in Computer Science Education	Research expanded to include machine learning and interdisciplinary approaches within computer science curricula. Efforts began addressing the inclusion of AI in software engineering education and exploring early-stage AI literacy tools.
2016–2019	Growing Interest in K-12 AI Literacy and Pedagogical Models	A surge in AI education initiatives targeted K-12 levels, with exploration of pedagogical designs, teacher readiness, and the inclusion of ethical considerations. Studies investigated hands-on learning, project-based activities, and the integration of AI across subjects, recognizing the need for interdisciplinary and critical approaches.
2020–2021	Establishing AI Literacy Frameworks and Teacher Preparation	Literature focused on defining AI literacy competencies, developing sustainable curricula, and preparing educators through professional development programs. Early implementations of AI education were studied, highlighting challenges in content delivery and the importance of human-centered AI pedagogy.
2022–2023	Advancements in AI Curriculum Design and Ethical Integration	Research emphasized curriculum reform with AI integration across educational levels, including adaptive, customized learning systems and intelligent tutoring. Ethical challenges such as algorithmic bias, data privacy, and equitable access became prominent. Teacher perspectives and readiness studies informed curriculum development and instructional strategies.
2024–2025	Personalized, Inclusive, and Generative AI in Education	Recent studies explore AI-driven adaptive learning platforms, generative AI tools like ChatGPT, and their impact on personalization, inclusivity, and engagement. Emphasis is placed on ethical frameworks, equitable access, teacher training, and integrating AI across interdisciplinary curricula. Innovations in AI-powered curriculum design and assessment are highlighted as transformative for future education.

3.2. Thematic Summary of the Studies

This section thematically maps the research landscape of the literature on AI in education, encompassing a diverse range of studies that explore AI education across K-12, higher education, and vocational contexts. The reviewed works employ various methodologies including systematic reviews, empirical studies, curriculum design, and qualitative analyses, with geographic representation spanning multiple continents. The comparison addresses critical dimensions such as curriculum integration, pedagogical effectiveness, inclusivity, ethical considerations, and educator preparedness, providing a comprehensive understanding relevant to the research questions on AI's role and impact in education.

Across the listed studies, AI curriculum integration is shifting from "add-on tools" toward systemic curriculum design, with most papers arguing that *AI literacy* should be treated as a foundational competence (not only a technical topic) and be embedded across subjects, assessment, and teacher education. Recurring threads appear across the various themes relating to curriculum integration depth (where and how AI is embedded), pedagogical effectiveness (what learning gains are reported or expected), and the "conditions of implementation," dominated by inclusivity/access, ethics/equity, and educator readiness. Table 2 presents the five overarching themes identified in the thematic analysis, together with their descriptions.

Table 2

Thematic Summary of the Studies

Theme	Theme Description
AI Literacy, educator preparedness and perceptions	AI literacy is broadly recognized as a critical competency for students, encompassing technical knowledge, ethical understanding, and responsible use of AI technologies. Curricula and programs emphasize interdisciplinary and age-appropriate AI education, aiming to equip learners with conceptual and applied skills to navigate an AI-driven future. Research indicates that AI literacy fosters motivation, ethical reflection, and problem-solving abilities, but also reveals gaps in assessment and educator preparedness. Teachers' attitudes, competency, and readiness significantly impact AI adoption in classrooms. Professional development programs and co-design initiatives support educators in understanding AI content and integrating AI tools effectively, while addressing concerns about workload, ethics, and instructional strategies. Collaborative frameworks foster teacher agency and adaptability across STEM and non-STEM disciplines.
Curriculum integration depth	AI integration in curricula spans from standalone AI courses to embedding AI concepts across subjects, promoting interdisciplinary approaches and project-based learning. Frameworks and models for AI curriculum development address content sequencing, competency frameworks, and contextual adaptation to diverse educational levels. Innovations include AI-assisted curriculum creation and personalized content generation, emphasizing the need to balance technological advances with pedagogical goals and human agency.
Pedagogical effectiveness	AI is explored both as an educational content area and as a tool to enhance teaching and learning processes. Applications include intelligent tutoring systems, automated assessments, AI-enhanced content creation, and facilitation of collaborative and active learning environments. This dual role requires pedagogical innovation and critical examination of AI's impact on teaching roles and student engagement.
Inclusivity and accessibility	AI-powered systems enable personalized learning experiences through adaptive platforms, intelligent tutoring, and real-time feedback, enhancing student engagement and academic outcomes. Studies demonstrate AI's role in tailoring instruction to individual needs and supporting diverse learners, including in STEAM and vocational education contexts. Despite benefits, challenges such as data privacy, algorithmic bias, and digital divides affect equitable implementation. Research highlights diverse AI education initiatives and challenges across countries and regions, reflecting variations in curriculum development, resource availability, and cultural contexts. Comparative studies inform adaptive strategies and underscore the need for context-sensitive frameworks that address local educational needs and global AI literacy standards. Efforts in developing countries emphasize capacity building, infrastructure development, and culturally relevant pedagogy.
Ethical and equity considerations	Ethical concerns including algorithmic bias, data privacy, and transparency are recurrent in AI education literature, alongside issues of equitable access and digital infrastructure disparities. Strategies for ethical AI integration emphasize inclusive design, governance frameworks, and policy development to mitigate risks and promote fairness. Addressing these challenges is crucial for sustainable and responsible AI use in education.

3.2.1. AI Literacy, Educator Preparedness and Perceptions: Training as the Dominant Implementation Bottleneck

The literature offers multiple integration frameworks emphasizing interdisciplinary design, alignment with existing curricula, and AI literacy as a multiliteracy spanning technical, conceptual, and socio-ethical competencies (Rüütmann & Läänemets, 2025; Stolpe & Hallström, 2024; Tadimalla & Maher, 2024). In harmony, teacher capacity is consistently presented as the main constraint on sustainable AI integration. Multiple sources explicitly call for professional development, competency frameworks, and teacher education redesign (Adıgüzel et al., 2023), often emphasizing that AI literacy requires both technical familiarity and socio-ethical facilitation skills (Black et al., 2024; Bulut et al., 2025; Bulut, 2026; Suna et al., 2025). Where educator perceptions are studied, findings tend to show interest and openness mixed with uncertainty, highlighting gaps in confidence, knowledge, and institutional support (Annuš, 2024; Karanfiloğlu & Bulut, 2025; Yue et al., 2024).

Teacher education-focused frameworks emphasize culturally responsive, equity-centered preparation and "community-wide" supports (Black et al., 2024; Bulut et al., 2026), while other studies stress digital competencies and practical pedagogical supports for classroom integration. Several works also argue that teachers' roles evolve toward orchestration, ethical guidance, and design leadership in hybrid human–AI learning environments (Han, 2026; Ramakrishnan et al., 2024).

3.2.2. Curriculum Integration Depth: From Discrete Modules to Cross-Curricular Architectures

Several studies propose frameworks that treat AI literacy as a curriculum-level construct rather than a single unit or elective. For example, work in education emphasizes embedding AI literacy within established curricular aims so that students learn AI as part of broader "technological literacy" and socio-technical understanding (Stolpe & Hallström, 2024). Related frameworks place AI within interdisciplinary socio-technical curricula that intentionally balance technical concepts (data, models, automation) with non-technical competencies (ethical reasoning, civic understanding, human agency) (Tadimalla & Maher, 2024).

A second integration pattern is AI as an educational technology engine of curriculum redesign, using AI to support adaptive pathways, competency-based progression (Birgili et al., 2025), and customized flexible learning structures (Anbumaheshwari et al., 2026). These studies align AI integration with outcome-based education and assessment modernization, emphasizing alignment between competencies, evidence of learning, and adaptive feedback loops.

A third pattern is contextual and system-level integration, including national/regional initiatives, guideline alignment (e.g., with UNESCO/SDGs), and infrastructural investment as prerequisites for equitable adoption (Li et al., 2024; Zhou et al., 2022). Across these, "integration depth" is framed less as a pedagogical choice and more as a governance and capacity-building agenda (Li et al., 2024). Overall, integration depth trends go toward cross-curricular AI literacy, adaptive/competency-based redesign and policy/infrastructure alignment (Li et al., 2024; Stolpe & Hallström, 2024).

3.2.3. Pedagogical Effectiveness: Gains Are Reported, but Often Conditionally

A consistent claim is that AI-supported curricula can strengthen problem-solving, creativity, critical thinking, engagement, and retention, particularly when learning is active (e.g., project-, inquiry-, game-, customized-, personalized- or design-based learning) (Dai, 2024; Ruth & İbrahim, 2025). Many K–12 based works emphasize hands-on experiences (camps, workshops, robotics, unplugged activities) as effective for building understanding and attitudes toward AI. Evidence syntheses generally report positive or moderate effects on learning outcomes and/or motivation, while also noting variability by tools, activity types, and evaluation methods (Garzón et al., 2025; Kim & Kwon, 2025).

At higher education and teacher education levels, AI is frequently portrayed as improving instructional efficiency, feedback, and personalization, yet several studies caution that benefits depend on teacher capability, curriculum coherence, and assessment integrity (Adıgüzel et al., 2026; Çela et al., 2025; Dubey & Crevar, 2025). Where AI is positioned as a curriculum co-designer (including generative AI), effectiveness is paired with warnings about hallucination/accuracy, plagiarism, and the need for human oversight (Bektik et al., 2024). In brief, pedagogical gains are commonly reported, especially for engagement and higher-order skills, but are repeatedly described as contingent on equity of access, ethical safeguards, and teacher preparedness (Bektik et al., 2024; Ruth & İbrahim, 2025).

3.2.4. Inclusivity and Accessibility: Equity as Both a Goal and a Constraint

Across the reviewed literature, AI-inclusivity is treated in two ways: first as an inclusion enabler through personalization, accessibility supports, Universal Design for Learning alignment, flexible pacing, and assistive affordances (Han, 2026; Tahura et al., 2026; Kohnke & Zaugg, 2025), and second as an equity risk due to digital divides, uneven infrastructure, cost barriers, and differential teacher readiness (Juyal et al., 2025; Li et al., 2024; Xiao et al., 2025).

Many papers explicitly highlight the digital divide (devices, connectivity, data access) as a core limiter of equitable AI literacy, cautioning that AI integration can magnify existing inequalities unless addressed through policy and investment (Juyal et al., 2025; Li et al., 2024; Xiao et al., 2025). Others extend equity beyond access to include cultural relevance, decolonization, and epistemic justice, arguing curriculum should reflect local contexts and diverse identities (Westover, 2025). To sum, inclusivity is widely positioned as non-negotiable, but most studies imply it requires system supports (infrastructure, governance, training, accessible design) rather than relying only on classroom-level good intentions (Li et al., 2024; Tahura et al., 2026; Westover, 2025).

3.2.5. Ethical and Equity Considerations: Privacy, Bias, Integrity, and Human Agency

Ethics appears as a unifying thread, though also standing out as a theme in its own right. Common focal points include:

- Data privacy/ownership and student protection (Baek & Wilson, 2024; Boumediene & Bouakkaz, 2025).
- Algorithmic bias and fairness plus mitigation strategies (Deckker et al., 2025; Kohnke & Zaugg, 2025; Ruth & İbrahim, 2025; Zhu & Fu, 2025).
- Academic integrity and transparency, especially in AI-driven assessment and generative AI use (Bektik et al., 2024).
- Human-centered AI and agency, emphasizing students' role in questioning, contextualizing, and governing AI use (Stolpe & Hallström, 2024).

A notable pattern is that ethics is rarely framed as a standalone unit. Many studies argue for ethics-infused pedagogy embedded in projects, dilemmas, reflective practice, and socio-technical reasoning (Tadimalla & Maher, 2024). In this framing, ethical competence is part of "what it means" to be AI literate (Casal-Otero et al., 2023; Chiu et al., 2024; Wang & Lester, 2023). Briefly stated, the ethical agenda is converging on privacy, bias/fairness, integrity and human-centered governance, with repeated calls for clear policies, transparency, and responsible implementation (Baek & Wilson, 2024; Zhu & Fu, 2025).

3.3. Strengths and Weaknesses of AI in Education

3.3.1. Personalized Learning and Adaptive Instruction

Across K–12 and higher education, AI-enabled adaptive platforms and intelligent tutoring systems are consistently associated with better tailoring of content and pacing, higher engagement, and improved performance, with added inclusivity benefits for varied learning styles and abilities (Deckker et al., 2025; Juyal et al., 2025; Ruth & İbrahim, 2025; Salendab et al., 2026; Xiao et al., 2025). However, benefits can be uneven where infrastructure and affordability constrain access, risking widened

disparities; there are also concerns that heavy dependence on AI may reduce human interaction and weaken critical thinking if pedagogy becomes "automation-led" rather than teacher-guided (Li et al., 2024; Zhu & Fu, 2025).

3.3.2. Curriculum Design and Integration Frameworks

The literature offers multiple integration frameworks emphasizing interdisciplinary design, alignment with existing curricula, and AI literacy as a multiliteracy spanning technical, conceptual, and socio-ethical competencies (Rüütmann & Läänemets, 2025; Stolpe & Hallström, 2024; Tadimalla & Maher, 2024). That said, many curriculum efforts remain fragmented, that's, lacking standardization, consistent thematic coverage, and sufficient treatment of societal/ethical implications. Disagreement (or absence) around shared AI literacy definitions and competency benchmarks continues to impede coherent curriculum development and comparability across contexts (Casal-Otero et al., 2023; Chiu et al., 2024; Michaeli et al., 2022).

3.3.3. Educator Preparedness and Professional Development

Studies repeatedly identify teacher learning (e.g., strengthening TPACK and assessment/pedagogy for AI) as pivotal for successful implementation, with well-designed programs improving educators' capacity to teach AI concepts and facilitate ethical discussion (Black et al., 2024; Fissore et al., 2024; Suna et al., 2025; Yau et al., 2023). However, a persistent skills-confidence-resource gap remains; many teachers report limited AI knowledge, insufficient instructional materials, and weak institutional support, particularly where infrastructure and professional learning ecosystems are underdeveloped (Addo, 2023).

3.3.4. Ethical Considerations and Equity

Ethical issues such as privacy, bias, fairness, and responsible use are widely recognized as essential curriculum content, with growing attention to embedding ethical reasoning and critical awareness into AI learning experiences (Krakowski et al., 2022; Stolpe & Hallström, 2024; Tahura et al., 2026; Yadav, 2024). Unfortunately, implementation lags behind aspiration: many educational AI systems remain opaque, insufficiently inclusive, and vulnerable to reproducing bias. Governance and policy frameworks for ethical AI in education are often described as incomplete or immature, limiting enforceable safeguards and accountability (Li et al., 2024; Yadav, 2024; Zhu & Fu, 2025).

3.3.5. Impact on Critical Thinking, Creativity, and Problem-Solving

Evidence suggests AI can support higher-order skills, especially when used in project-based learning, simulations, and STEAM/technology education contexts that require authentic inquiry and iterative design (Espinoza, 2026; Kotsari & Smyrnaiou, 2025; Ruth & İbrahim, 2025). The same tools though may erode these skills if used

uncritically (e.g., substituting AI output for reasoning), encouraging passive consumption and shallow engagement rather than student-led inquiry and creative struggle (Deckker et al., 2025; Zhu & Fu, 2025).

3.3.6. Methodological Rigor and Research Gaps

The evidence base is methodologically diverse (systematic reviews, empirical studies, case analyses), with some work providing robust quantitative indicators of positive effects on learning outcomes (Familoni & Onyebuchi, 2024). Common limitations include small samples, short interventions, limited longitudinal tracking, and reliance on self-reported outcomes, which constrains generalizability and makes long-term impact claims uncertain, thereby supporting calls for larger-scale, longer-term, and more rigorous designs (Animashaun et al., 2024; Kim & Kwon, 2025; Okolo, 2024; Rizvi et al., 2023).

3.3.7. Technological Tools and Resources

A broad ecosystem of tools (tutors, chatbots, adaptive systems, analytics) is reported to improve efficiency, feedback quality, and personalization, often positioned as support for diverse learners and teachers' workload management (Kwid et al., 2024). Tool integration though is frequently hindered by interoperability issues, technical constraints, and insufficient teacher support; equity problems persist because infrastructure gaps limit deployment and sustained use, especially in under-resourced contexts (Li et al., 2024; Perse, 2025).

3.4. Ongoing Discussions on AI in Education

Most studies concur on the importance and benefits of integrating AI into education, highlighting its role in enhancing personalized learning, inclusivity, and adaptive curriculum design. There is broad consensus that ethical considerations and teacher preparedness are critical challenges to address for successful AI adoption. However, divergences exist regarding the depth of AI integration in curricula, with some studies emphasizing technical skills while others advocate for interdisciplinary and socio-ethical approaches. Disparate contexts, educational levels, and methodological focuses contribute to variations in reported challenges and implementation strategies. Below is a summary list of contemporary areas of discussion pertaining to the AI integration in education.

3.4.1. AI Literacy, Educator Preparedness and Perceptions

Teacher readiness, confidence, and attitudes are consistently identified as decisive for successful AI integration; professional development and scaffolded support are repeatedly recommended (Addo, 2023; Black et al., 2024; Fissore et al., 2024; Suna et al., 2025; Yue et al., 2024). Other work highlights substantial gaps in AI knowledge and confidence that can contribute to resistance or superficial/ineffective use, with

perceived workload and technology acceptance varying across contexts (Masih et al., 2025). Differences are plausibly driven by variability in teacher education programs, institutional resourcing and infrastructure, and cultural norms shaping technology adoption and workload expectations.

3.4.2. Curriculum Integration Depth

Many studies support embedding AI literacy and tools in education, explicitly pairing technical learning with ethical understanding, and using either cross-curricular integration or standalone AI subject structures to build computational thinking and problem-solving (Casal-Otero et al., 2023; Heo, 2025; Rüütmann & Läänemets, 2025; Stolpe & Hallström, 2024; Tadimalla & Maher, 2024; Weng et al., 2024). Some papers prioritize AI as a discrete technical discipline (often CS/higher education), while others foreground socio-technical, interdisciplinary integration (Aliabadi et al., 2023; Michaeli et al., 2022; Mishra & Siy, 2020; Tadimalla & Maher, 2024). Differences are largely attributable to educational level (K–12 vs higher education), regional policy expectations, and disciplinary traditions (technical specialization vs interdisciplinary literacy).

3.4.3. Pedagogical Effectiveness

AI is frequently reported to improve engagement and learning outcomes via adaptive/personalized platforms and project-based, collaborative learning designs; hands-on, scaffolded, and human–AI collaboration approaches are repeatedly positioned as effective (Dai, 2024; Deckker et al., 2025; Ruth & İbrahim, 2025). Some studies warn that uncritical or heavy reliance on AI may weaken critical thinking/creativity, and others flag implementation issues such as insufficient formative feedback or instructional fit (Akram et al., 2022; Masih et al., 2025). Reported effectiveness varies with pedagogical design quality, duration/intensity of interventions, and the measures used to assess learning (e.g., short-term performance vs deeper reasoning outcomes). On the other hand, it should be noted that studies with counter arguments imply critical insights. Contrary to the 'cognitive atrophy' hypothesis, emerging research suggests that when AI is integrated as a 'digital scaffold,' it actually catalyzes higher-order critical thinking by automating procedural redundancies and providing real-time, personalized formative feedback that encourages students to move beyond rote memorization into complex, iterative problem-solving (Gerlich, 2025; Magwa, 2026; Patrick et al., 2025; Yang & Niu, 2026).

3.4.4. Inclusivity and Accessibility

Many sources frame AI as a lever for inclusion, that is, supporting diverse learners, accessibility needs, and equity goals, often recommending Universal Design for Learning-aligned approaches (Han, 2026; Kohnke & Zaugg, 2025; Motta et al., 2025; Tahura et al., 2026). Persistent evidence of uneven access and digital divides,

particularly in under-resourced schools and developing regions, challenges equitable implementation (Li et al., 2024; Masih et al., 2025; Westover, 2025). Socioeconomic conditions, infrastructure and connectivity constraints, and policy/investment gaps shape whether AI inclusion benefits are realized at scale.

3.4.5. Ethical and Equity Considerations

Ethical issues such as privacy, bias, transparency, and responsible use are treated as central to AI adoption, with broad support for integrating ethics alongside technical instruction (Boumediene & Bouakkaz, 2025; Krakowski et al., 2022; Stolpe & Hallström, 2024; Tadimalla & Maher, 2024; Yadav, 2024). Some studies argue ethics remains under-implemented in practice, and others emphasize that teacher capacity to facilitate ethical discussion is a limiting factor (Suna et al., 2025). Variation reflects differing policy maturity and governance, uneven educator preparation, and whether a study focuses on ethical ideals/frameworks versus classroom enactment.

4. Discussion

4.1. Theoretical and Practical Implications

4.1.1. Theoretical Implications

The integration of AI into education supports the evolving conceptualization of technological literacy as a multiliteracy that includes technical skills, technological scientific knowledge, and socio-ethical understanding. This aligns with frameworks emphasizing AI literacy as encompassing both technical competencies and ethical considerations (Casal-Otero et al., 2023; Stolpe & Hallström, 2024; Tadimalla & Maher, 2024). AI's role in fostering critical thinking, creativity, and problem-solving within STEAM and STEM education confirms constructivist and learner-centered pedagogical theories, highlighting AI as a tool that enables personalized and adaptive learning experiences (Espinoza, 2026; Kotsari & Smyrnaiou, 2025; Ruth & İbrahim, 2025).

The findings underscore the necessity of a transdisciplinary and holistic approach to AI education, integrating AI concepts across curricula rather than isolating them as standalone subjects. This challenges traditional disciplinary boundaries and supports theories advocating for interdisciplinary learning to address complex real-world problems (Aliabadi et al., 2023; Casal-Otero et al., 2023; Michaeli et al., 2022). Ethical considerations and equity issues in AI adoption emphasize the importance of embedding responsible AI principles within educational frameworks, supporting theoretical models that advocate for fairness, transparency, and inclusivity in technology-enhanced learning (Revolusi & Febriandy, 2025; Tian, 2024).

The evolving role of educators in AI-enhanced classrooms, shifting from knowledge transmitters to facilitators and ethical guides, aligns with socio-constructivist theories and highlights the importance of teacher agency in mediating AI's impact on learning (Grubaugh & Levitt, 2023; Ramakrishnan et al., 2024). The limited empirical assessment of AI learning outcomes, especially in K-12 settings, points to a theoretical gap in understanding how AI literacy develops cognitively and affectively, suggesting a need for more rigorous, longitudinal research designs (Bulut et al., 2026; Casal-Otero et al., 2023; Rizvi et al., 2023; Yue et al., 2022).

4.1.2. Practical Implications

AI integration in education necessitates comprehensive teacher professional development programs that enhance AI literacy, pedagogical skills, and ethical awareness to ensure effective curriculum implementation and instructional practices (Black et al., 2024; Fissore et al., 2024; Yue et al., 2024). Policymakers and educational institutions should prioritize equitable access to AI technologies and infrastructure to mitigate digital divides and ensure all learners benefit from AI-enhanced personalized learning environments (Li et al., 2024; Masih et al., 2025; Westover, 2025). An elaboration-worthy point also lies in teacher position (teacher agency) and defining, measuring and assessing learning outcomes. As artificial intelligence increasingly assumes the burden of content delivery and procedural feedback, the teacher's necessity is reaffirmed not as a distributor of information but as a pedagogical orchestrator and socio-emotional anchor who provides the ethical mentorship and diagnostic intervention that machines cannot replicate, thereby necessitating a radical shift in educational assessment from the measurement of static, AI-reproducible final products toward the evaluation of the iterative, process-based competencies and critical literacies essential for navigating an automated world (OECD, 2026).

Curriculum designers are encouraged to adopt adaptive, learner-centered frameworks that leverage AI-driven tools for personalized content delivery, real-time feedback, and formative assessment, thereby improving student engagement and academic outcomes (Anbumaheshwari et al., 2026; Animashaun et al., 2024). The co-design of AI curricula with educators across disciplines fosters relevance, inclusivity, and practical applicability, supporting scalable and context-sensitive AI education models that address diverse learner needs (Li et al., 2024; Lin & Van Brummelen, 2021). Ethical guidelines and governance frameworks must be established to address data privacy, algorithmic bias, and academic integrity concerns, ensuring responsible AI use in educational settings and maintaining trust among stakeholders (Baek & Wilson, 2024; Revolusi & Febriandy, 2025; Yadav, 2024). Industry-academia collaborations and mentorship programs can enhance AI education by providing real-world applications, resources, and support, thereby bridging the gap between educational outcomes and workforce demands (Chklovski et al., 2021; Crevar et al., 2026; Saddam & Hasan, 2024).

4.2. Summary of Research Limitations and Future Priorities

4.2.1. Limitations

Research in AI-in-education faces several interconnected challenges that limit the generalizability and depth of current findings. Methodologically, many studies suffer from small sample sizes that reduce statistical power and confidence in replication (Alvarez et al., 2022; Rizvi et al., 2023; Yue et al., 2022), a lack of longitudinal data to track long-term impacts (Deckker et al., 2025; Leddy & Creanor, 2024; Masih et al., 2025), and an insufficient assessment of learning outcomes that relies too heavily on self-reported or qualitative data rather than objective measures (Casal-Otero et al., 2023; Rizvi et al., 2023; Yue et al., 2022). These issues are compounded by geographic bias and technological infrastructure gaps, which concentrate evidence in well-resourced regions and hinder global transferability (Casal-Otero et al., 2023; Heo, 2025; Li et al., 2024; Masih et al., 2025; Song et al., 2022). Furthermore, implementation is often hampered by under-addressed teacher preparedness (Fissore et al., 2024; Motta et al., 2025; Suna et al., 2025; Yue et al., 2024) and a lack of standardized curriculum frameworks, making it difficult to compare results across fragmented literacy definitions (Casal-Otero et al., 2023; Lee & Kwon, 2024; Zhou et al., 2022). Finally, the field must contend with inconsistently treated ethical considerations (Deckker et al., 2025; Revolusi & Febriandy, 2025; Xiao et al., 2025; Yadav, 2024), concerns regarding learner passivity and overreliance on AI tools (Leddy & Creanor, 2024; Masih et al., 2025), and limited interdisciplinary approaches that often isolate research within computer science at the expense of holistic socio-ethical integration (Aliabadi et al., 2023; Mishra & Siy, 2020; Tadimalla & Maher, 2024).

4.2.2. Future Priorities

To advance AI education, researchers and practitioners must bridge several critical gaps by prioritizing the standardization of AI literacy frameworks to create validated, interdisciplinary competencies across K–12 and higher education (Casal-Otero et al., 2023; Chiu et al., 2024; Stolpe & Hallström, 2024). This effort requires addressing educator preparedness through scalable, context-sensitive professional development (Black et al., 2024; Chiu et al., 2024; Fissore et al., 2024; Yue et al., 2024) and moving beyond theoretical discussions of ethical AI integration to implement practical governance and pedagogical models for bias mitigation (Baek & Wilson, 2024; Krakowski et al., 2022; Tadimalla & Maher, 2024; Yadav, 2024). Bridging the digital divide to ensure equitable access necessitates longitudinal tracking of infrastructure disparities and the development of low-cost tools (Juyal et al., 2025; Kohnke & Zaugg, 2025; Li et al., 2024; Perse, 2025), while shifting away from short-term studies toward longitudinal research that measures cognitive and affective outcomes across diverse

populations (Kim & Kwon, 2025; Okolo, 2024; Rizvi et al., 2023). Future work should also foster interdisciplinary integration that embeds AI across the humanities and sciences (Aliabadi et al., 2023; Mertala et al., 2024; Tadimalla & Maher, 2024) while maintaining a human-centered pedagogy that protects critical thinking and social-emotional learning from AI overreliance (Asy'ari & Sharov, 2024; Masih et al., 2025; Zhu & Fu, 2025). Furthermore, it is essential to adapt curricula for diverse and marginalized learners using inclusive design (Albert & Son, 2026; Han, 2026; Kohnke & Zaugg, 2025; Tahura et al., 2026), resolve usability and integration challenges through user-centered design (Annuš, 2024; Kwid et al., 2024; Lin & Van Brummelen, 2021), and develop robust AI-enabled assessment and feedback mechanisms to support real-time instructional decision-making (Akram et al., 2022; Dai, 2024; Okolo, 2024).

Conclusion and Overall Synthesis

The collective body of literature illustrates that integrating artificial intelligence into education fundamentally transforms curricular design, pedagogical approaches, and learner engagement across educational levels. AI's capacity to enable personalized, adaptive, and learner-centric instruction emerges as a central theme, effectively enhancing student motivation, critical thinking, creativity, and problem-solving skills. This tailored approach not only addresses diversity in learner cognition but also promotes inclusivity by supporting marginalized groups and learners with disabilities. However, the promise of personalization is tempered by persistent challenges related to digital equity, infrastructure limitations, and varying degrees of educator preparedness, which may inadvertently widen educational disparities if unaddressed.

Curriculum integration of AI is recognized as a multifaceted endeavor, requiring interdisciplinary frameworks that encompass technical competencies, socio-ethical understanding, and conceptual AI literacy. The literature underscores the importance of embedding ethics education alongside technical content to foster responsible AI use and critical societal awareness. Although several curriculum models and frameworks have been proposed, the lack of standardization and modular, scalable AI curricula remains a significant obstacle to widespread and coherent adoption. Teacher involvement in curriculum co-design is identified as essential to ensure curricular relevance, adaptability across disciplines, and effective pedagogy.

Educator readiness is another critical factor shaping AI integration success. While teachers generally express positive attitudes toward AI's educational potential, many report insufficient knowledge, skills, and access to resources needed for effective implementation. Professional development programs that build technological pedagogical content knowledge and ethical awareness are imperative for

empowering educators as facilitators of AI literacy and ethical instruction. Collaborative and sustained training initiatives, coupled with institutional support, are necessary to bridge these gaps.

Ethical and equity concerns permeate the discourse around AI in education. Issues such as data privacy, algorithmic bias, transparency, and fairness require systematic attention through policy development and curriculum design to prevent exacerbation of existing inequalities. Human-centered AI approaches and inclusivity principles, including Universal Design for Learning, are advocated to guide ethical AI deployment in educational contexts.

Overall, AI's integration into education holds transformative potential, fostering dynamic, personalized, and equitable learning experiences. Realizing this potential demands comprehensive frameworks that harmonize curriculum innovation, educator preparedness, ethical safeguards, and infrastructural equity. Future research should focus on longitudinal impacts, scalable implementation strategies, and nuanced assessments to deepen understanding and optimize AI's role in preparing learners for an AI-driven future.

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